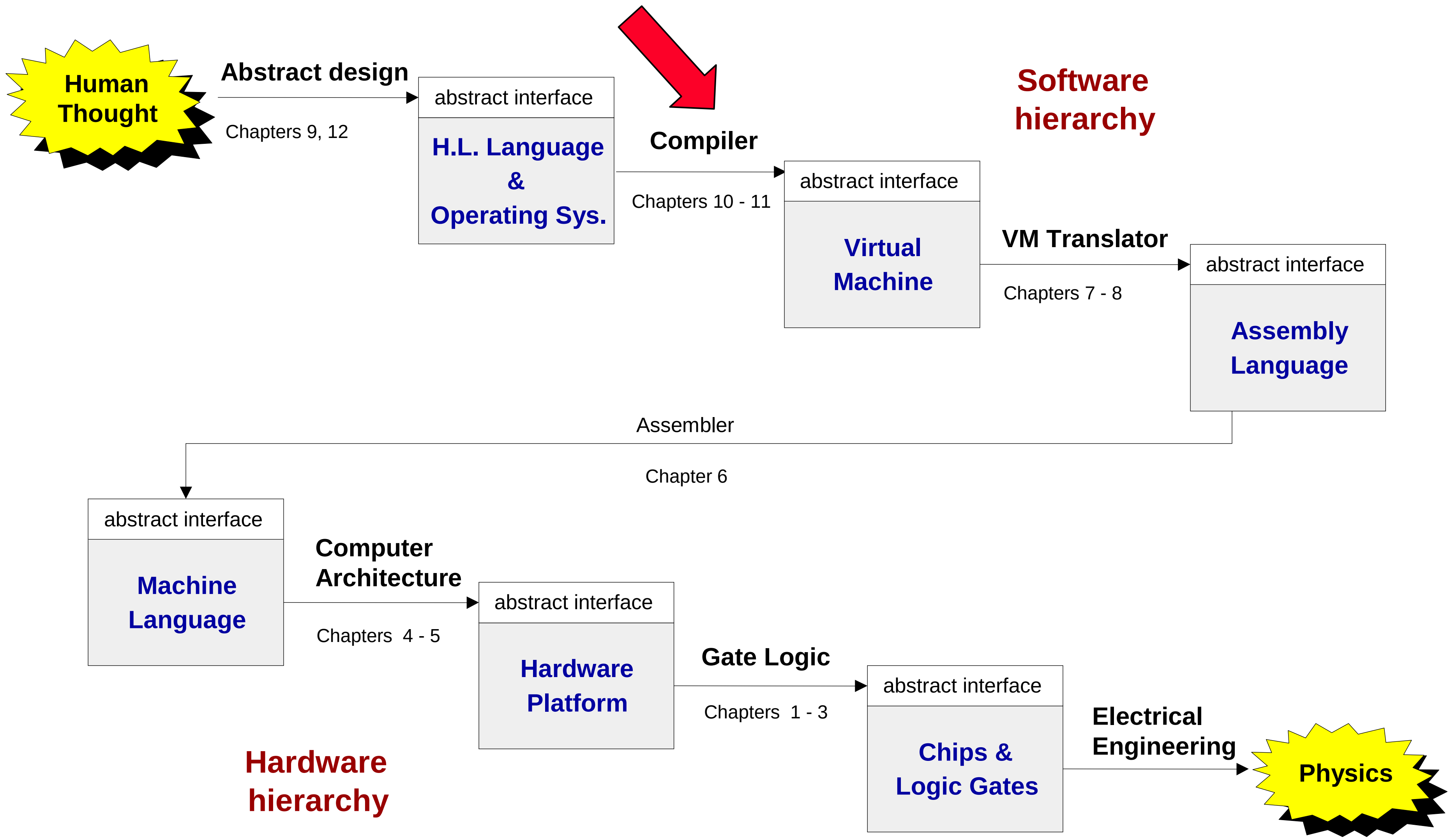
Compiler I: Sytnax Analysis

Course map


Human
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Abstract design
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Compiler
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abstract interface
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hierarchy

Motivation: Why study about compilers?

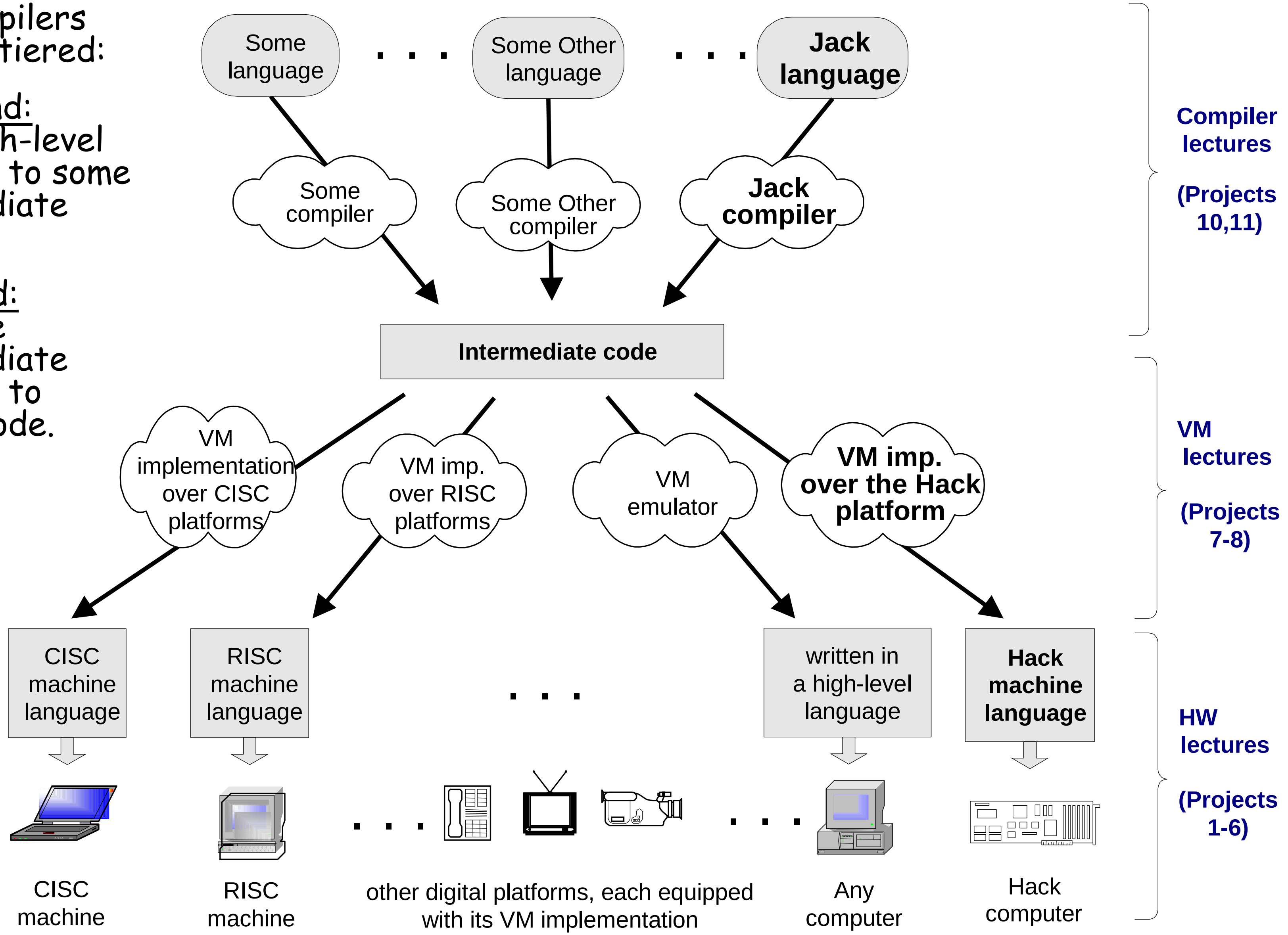
Because Compilers …

- Are an essential part of computer science
- Are an essential part of computational linguistics
- Are implemented using classical programming techniques
- Employ great software engineering principles
- Train you in developing software for transforming one structure to another (programs, files, transactions, …)

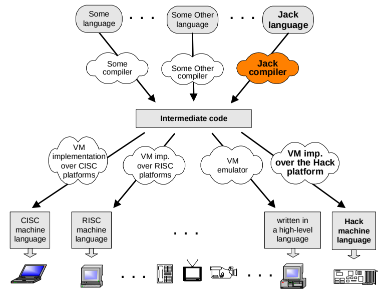
The big picture

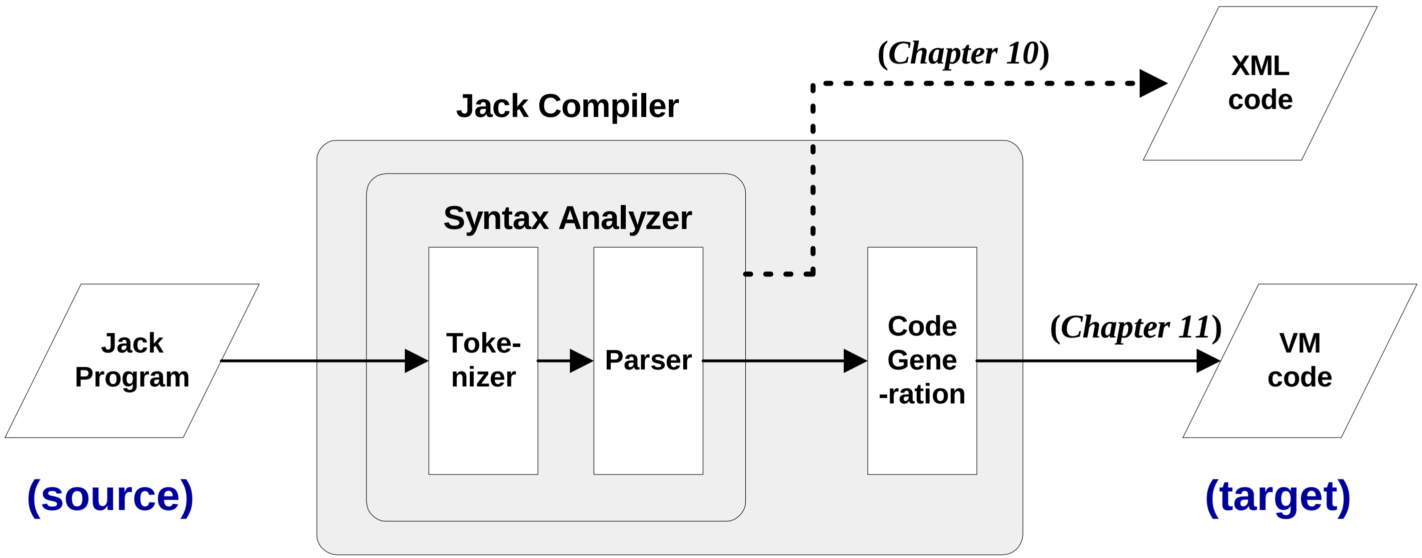
Modern compilers are two-tiered:

- Front-end: from high-level language to some intermediate language
- Back-end: from the intermediate language to binary code.



Compiler architecture (front end)





- Syntax analysis: understanding the semantics implied by the source code
  - Tokenizing: creating a stream of "atoms"
  - Parsing: matching the atom stream with the language grammar

  XML output = one way to provide evidence that the syntax analyzer works

- Code generation: reconstructing the semantics using the syntax of the target code.

Tokenizing / Lexical analysis

Code fragment

```
while (count<=100) { /** demonstration */
      count++;
      // body of while continues
      ...
```

Tokens

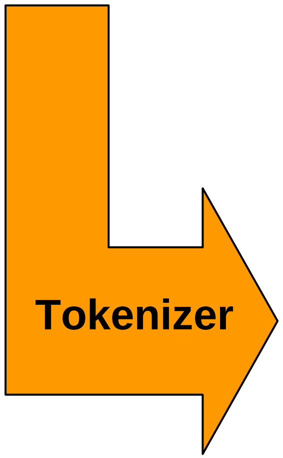
```
while
(
count
<=
100
)
{
count
++
;
...
```

- Remove white space
- Construct a token list (language atoms)
- Things to worry about:
  - Language specific rules:
    e.g. how to treat "++"
  - Language specific token types:
    keyword, identifier, operator, constant, ...
- While we are at it, we can have the tokenizer record not only the atom, but also its lexical classification (as defined by the source language grammar).

Jack Tokenizer

Source code

```
if (x < 153) {let city = ”Paris”;}
```



Tokenizer’s output

```
<tokens>
  <keyword> if </keyword>
  <symbol> ( </symbol>
  <identifier> x </identifier>
  <symbol> &lt; </symbol>
  <integerConstant> 153 </integerConstant>
  <symbol> ) </symbol>
  <symbol> { </symbol>
  <keyword> let </keyword>
  <identifier> city </identifier>
  <symbol> = </symbol>
  <stringConstant> Paris </stringConstant>
  <symbol> ; </symbol>
  <symbol> } </symbol>
</tokens>
```

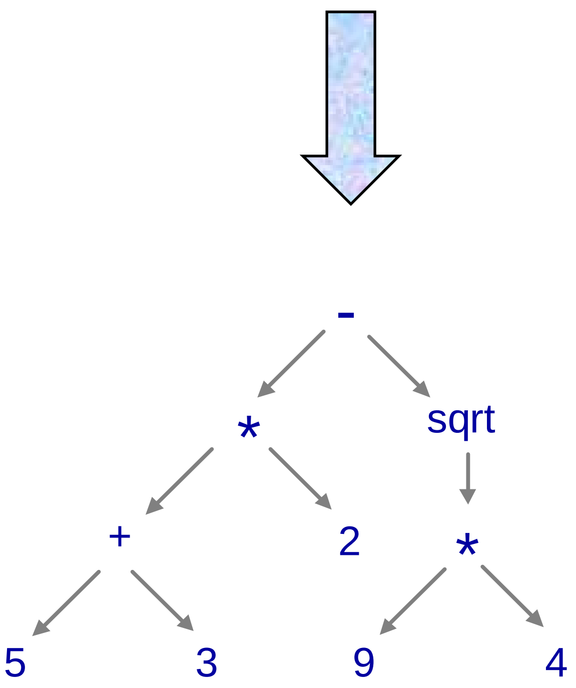
Parsing

- Each language is characterized by a *grammar*
- A text is given:
  - The parser, using the grammar, can either accept or reject the text
  - In the process, the parser performs a complete structural analysis of the text
- The language can be:
  - Context-dependent (English, …)
  - Context-free (Jack, …).

Examples

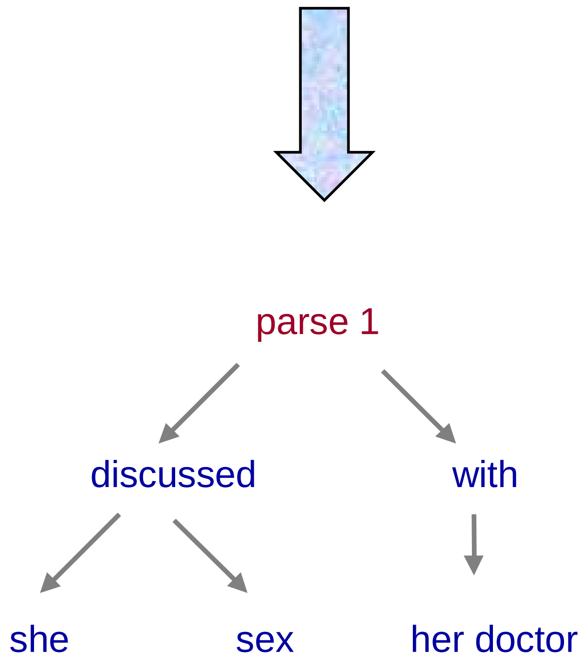
context free

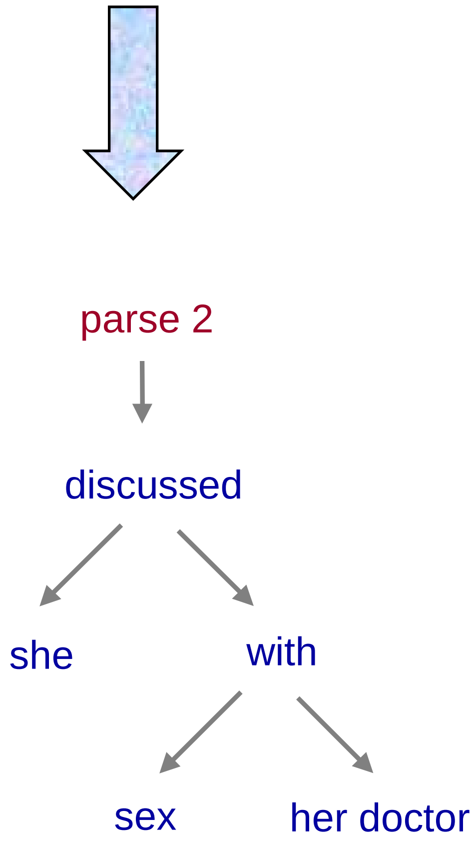
```
(5+3)*2 – sqrt(9*4)
```



context dependent

```
she discussed sex with her doctor
```





More examples of context dependent parsing

Time flies like an arrow

We gave the monkeys the bananas because they were hungry

We gave the monkeys the bananas because they were over-ripe

I never said she stole my money

<u>I</u> never said she stole my money

I <u>never</u> said she stole my money

I never <u>said</u> she stole my money

I never said <u>she</u> stole my money

I never said she <u>stole</u> my money

I never said she stole <u>my</u> money

I never said she stole my <u>money</u>

A typical grammar of a typical C-like language

Grammar

```
program:         statement;

statement:         whileStatement
                 | ifStatement
                 | // other statement possibilities ...
                 | '{' statementSequence '}'

whileStatement: 'while' '(' expression ')' statement

ifStatement:       simpleIf
                 | ifElse

simpleIf:        'if' '(' expression ')' statement

ifElse:          'if' '(' expression ')' statement
                 'else' statement

statementSequence:    ''    // null, i.e. the empty sequence
                    | statement ';' statementSequence

expression:        // definition of an expression comes here

// more definitions follow
```

Code sample

```
while (expression) {
  if (expression)
     statement;
     while (expression) {
        statement;
        if (expression)
           statement;
     }
  while (expression) {
     statement;
     statement;
  }
}

if (expression) {
   statement;
   while (expression)
      statement;
      statement;
   }
   if (expression)
      if (expression)
         statement;
}
```

- Simple (terminal) forms / complex (non-terminal) forms
- Grammar = set of rules on how to construct complex forms from simpler forms
- Highly recursive.

Parse tree

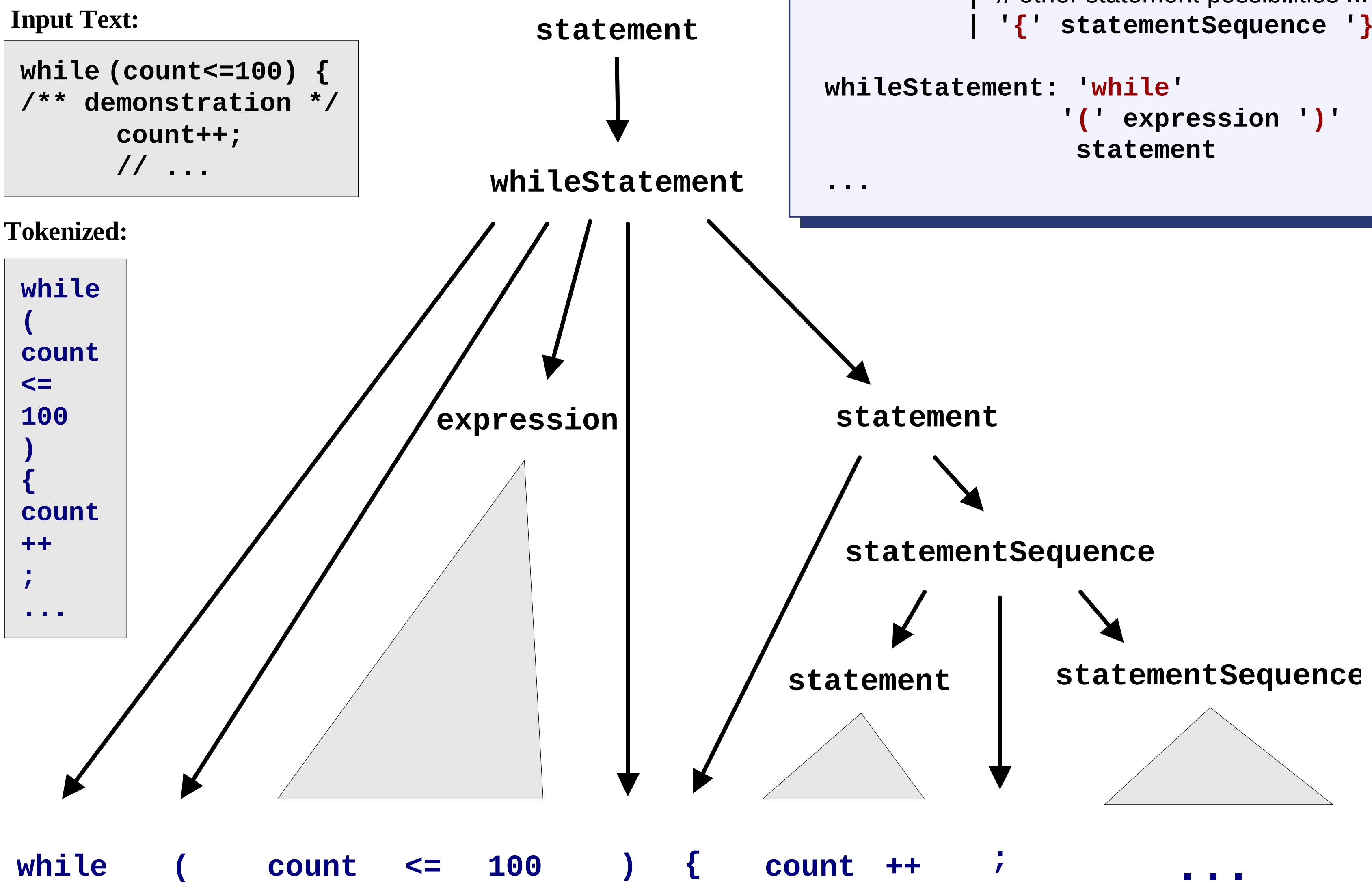
```
program:  statement;

statement: whileStatement
         | ifStatement
         | // other statement possibilities ...
         | '{' statementSequence '}'

whileStatement: 'while'
                '(' expression ')'
                statement
...
```

Input Text:

```
while (count<=100) {
/** demonstration */
      count++;
      // ...
```

Tokenized:

```
while
(
count
<=
100
)
{
count
++
;
...
```



Recursive descent parsing

```
...
statement:   whileStatement
           | ifStatement
           | ...            // other statement possibilities follow
           | '{' statementSequence '}'

whileStatement: 'while' '(' expression ')' statement

ifStatement: ...            // if definition comes here

statementSequence:  ''    // null, i.e. the empty sequence
                  | statement ';' statementSequence

expression: ...    // definition of an expression comes here

...                // more definitions follow
```

code sample

```
while (expression) {
    statement;
    statement;
    while (expression) {
        while (expression)
            statement;
            statement;
    }
}
```

- Highly recursive
- LL(0) grammars: the first token determines in which rule we are
- In other grammars you have to look ahead 1 or more tokens
- Jack is almost LL(0).

- `parseStatement()`
- `parseWhileStatement()`
- `parseIfStatement()`
- `parseStatementSequence()`
- `parseExpression()`.

A linguist view on parsing

Parsing:

One of the mental processes involved in sentence comprehension, in which the listener determines the syntactic categories of the words, joins them up in a tree, and identifies the subject, object, and predicate, a prerequisite to determining who did what to whom from the information in the sentence.

(Steven Pinker,
The Language Instinct)

The Jack grammar

Lexical elements:	The Jack language includes five types of terminal elements (tokens):
keyword:	'**class**' | '**constructor**' | '**function**' | '**method**' | '**field**' | '**static**' | '**var**' | '**int**' | '**char**' | '**boolean**' | '**void**' | '**true**' | '**false**' | '**null**' | '**this**' | '**let**' | '**do**' | '**if**' | '**else**' | '**while**' | '**return**'
symbol:	'**{**' | '**}**' | '**(**' | '**)**' | '**[**' | '**]**' | '**.**' | '**,**' | '**;**' | '**+**' | '**-**' | '*****' | '**/**' | '**&**' | '**|**' | '**<**' | '**>**' | '**=**' | '**~**'
integerConstant:	A decimal number in the range 0 .. 32767.
StringConstant	'"' A sequence of Unicode characters not including double quote or newline '"'
identifier:	A sequence of letters, digits, and underscore ('_') not starting with a digit.
Program structure:	A Jack program is a collection of classes, each appearing in a separate file. The compilation unit is a class. A class is a sequence of tokens structured according to the following context free syntax:
class:	'**class**' className '**{**' classVarDec* subroutineDec* '**}**'
classVarDec:	('**static**' | '**field**') type varName ('**,**' varName)* '**;**'
type:	'**int**' | '**char**' | '**boolean**' | className
subroutineDec:	('**constructor**' | '**function**' | '**method**') ('**void**' | type) subroutineName '**(**' parameterList '**)**' subroutineBody
parameterList:	((type varName) ('**,**' type varName)*)?
subroutineBody:	'**{**' varDec* statements '**}**'
varDec:	'**var**' type varName ('**,**' varName)* '**;**'
className:	identifier
subroutineName:	identifier
varName:	Identifier

'x':	x appears verbatim
x:	x is a language construct
x?:	x appears 0 or 1 times
x*:	x appears 0 or more times
x|y:	either x or y appears
(x,y):	x appears, then y.

The Jack grammar (cont.)

Statements:

statements:	statement*
statement:	letStatement | ifStatement | whileStatement | doStatement | returnStatement
letStatement:	'**let**' varName ('**[**' expression '**]**')? '=' expression '**;**'
ifStatement:	'**if**' '**(**' expression '**)**' '**{**' statements '**}**' ('**else**' '**{**' statements '**}**')?
whileStatement:	'**while**' '**(**' expression '**)**' '**{**' statements '**}**'
doStatement:	'**do**' subroutineCall '**;**'
ReturnStatement	'**return**' expression? '**;**'

Expressions:

expression:	term (op term)*
term:	integerConstant | stringConstant | keywordConstant | varName | varName '**[**' expression '**]**' | subroutineCall | '**(**' expression '**)**' | unaryOp term
subroutineCall:	subroutineName '**(**' expressionList '**)**' | (className | varName) '**.**' subroutineName '**(**' expressionList '**)**'
expressionList:	(expression ('**,**' expression)*)?
op:	'+' | '-' | '*' | '/' | '&' | '|' | '<' | '>' | '='
unaryOp:	'-' | '~'
KeywordConstant:	'**true**' | '**false**' | '**null**' | '**this**'

'x':	x appears verbatim
x:	x is a language construct
x?:	x appears 0 or 1 times
x*:	x appears 0 or more times
x|y:	either x or y appears
(x,y):	x appears, then y.

Jack syntax analyzer in action

```
Class Bar {
   method Fraction foo(int y) {
     var int temp; // a variable
     let temp = (xxx+12)*-63;
      ...
   ...
```

Syntax analyzer

```
<varDec>
  <keyword> var </keyword>
  <keyword> int </keyword>
  <identifier> temp </identifier>
  <symbol> ; </symbol>
</varDec>
<statements>
  <letStatement>
    <keyword> let </keyword>
    <identifier> temp </identifier>
    <symbol> = </symbol>
    <expression>
       <term>
         <symbol> ( </symbol>
         <expression>
           <term>
             <identifier> xxx </identifier>
           </term>
           <symbol> + </symbol>
           <term>
             <int.Const.> 12 </int.Const.>
           </term>
    </expression>
    ...
```

Syntax analyzer

- Using the language grammar, a programmer can write a syntax analyzer program
- The syntax analyzer takes a source text file and attempts to match it on the language grammar
- If successful, it generates a parse tree in some structured format, e.g. XML.

The syntax analyzer's algorithm shown in this slide:

- If xxx is non-terminal, output:

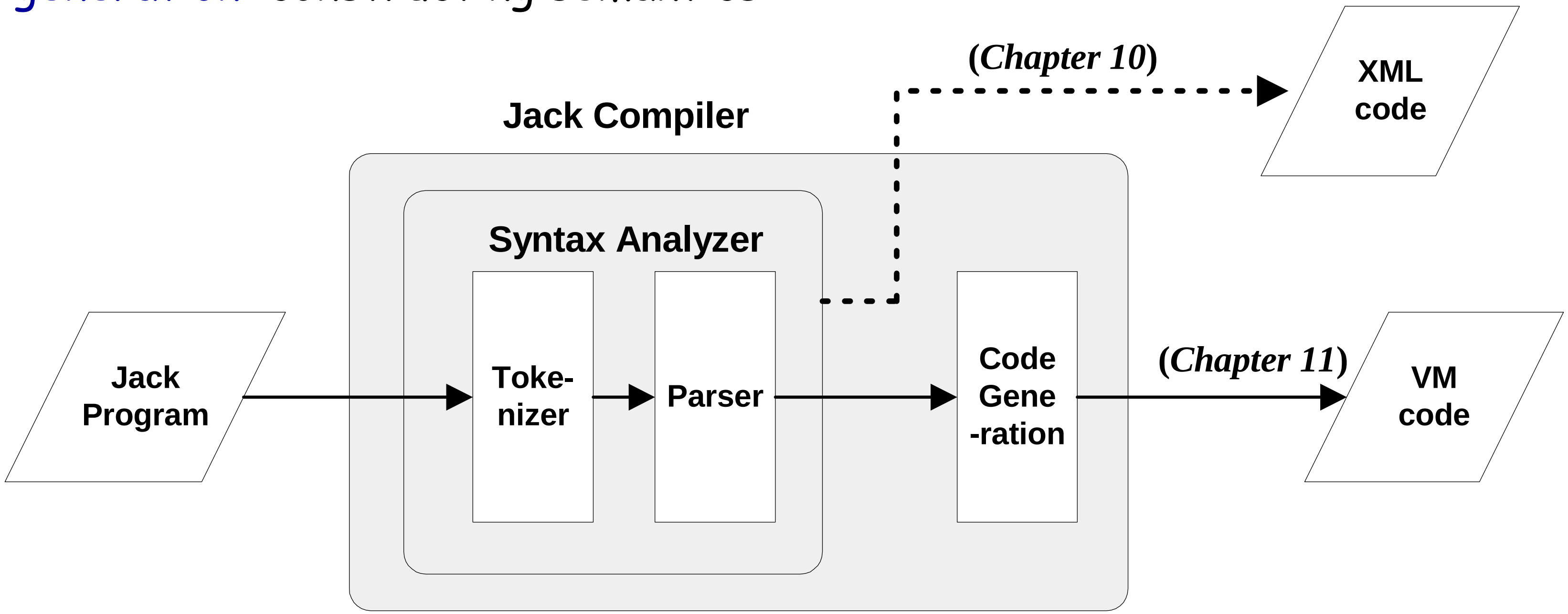
  <xxx>
  Recursive code for the body of **xxx**
  </xxx>

- If xxx is terminal (keyword, symbol, constant, or identifier) , output:

  <xxx>
  xxx value
  </xxx>

Summary and next step

- *Syntax analysis*: understanding syntax
- *Code generation*: constructing semantics



The code generation challenge:

- Extend the syntax analyzer into a full-blown compiler that, instead of generating passive XML code, generates executable VM code
- Two challenges: (a) handling data, and (b) handling commands.

Perspective

- The parse tree can be constructed on the fly
- Syntax analyzers are typically built using tools like:
  - **`Lex`** for tokenizing
  - **`Yacc`** for parsing
- The Jack language is intentionally simple:
  - Statement prefixes: **`let`**, **`do`**, ...
  - No operator priority
  - No error checking
  - Basic data types, etc.
- Typical languages are richer, requiring more powerful compilers
- The Jack compiler: designed to illustrate the key ideas that underlie modern compilers, leaving advanced features to more advanced courses
- Industrial-strength compilers:
  - Have good error diagnostics
  - Generate tight and efficient code
  - Support parallel (multi-core) processors.